

Physicochemical and Mechanical Characterisation of Ceramic Materials Obtained from a Mixture of Silica, Feldspars and Clay Material of the Douala Region in Cameroon (Central Africa)

G.F. Ngon ngon^{1*}, G.L. Lecomte nana², R. Yongue fouateu³, G. Lecomte², P. Bilong³

¹Laboratory of Geoscience and Environment, Department of Earth Sciences, Faculty of Science, University of Douala, P.O. Box 24157 Douala, Cameroon

²Centre Européen de la Céramique, Laboratoire Groupe d'Etude des Matériaux Hétérogènes (GEMH), Ecole Nationale Supérieure de Céramique Industrielle (ENSCI) 12 rue Atlantis, 87078 Limoges, France

³Laboratory of Applied Geology-Metallogeny, Department of Earth Sciences, Faculty of Science, University of Yaounde I, P.O. Box 812 Yaoundé, Cameroon

*gngonngon@yahoo.fr

Abstract

Ceramic building materials were obtained by mixing silica, feldspars, and kaolinitic and illitic clay of Missole 2 area, meaning 20% of silica, 15% of Na-feldspar and 15% of mixed-feldspar. Samples were shaped from uniaxial pressing of wet granules and then fired up to 1150 °C. They were characterised by porosity, bulk density, microstructure and flexural strength. Structures of fired products containing mullite, hematite and quartz crystals embedded into a porous and interconnected microcrystalline matrix of both clayey and mixed materials. However, dense particles were developed within the matrix of the mixture and decreased the quantity and diameter of pores. Average values of clay ceramics were 2-8 MPa and were lower than flexural strength values of the mixture (15-20 MPa).

Keywords

Cameroon; Feldspar; Kaolinitic and Illitic Clays; Silica

Introduction

Ceramic industry in tropical region uses intensively kaolinitic clay materials due to their extreme presence in the many clayey deposit types known as sedimentary, alluvial, and residual. However, these clayey materials often present poor mechanical characteristics (weak flexural strength with a great fragility) partly linked to the chemical and mineralogical nature, and particularly to the lack of control of raw materials and also for different stages of

the ceramic process (Traoré Karfa et al., 2007). Several studies have highlighted their performances as construction materials and in the manufacturing of ceramics with the help of clayey mixtures (Traoré Karfa et al., 2007) or chemical and mineral additives like calcite (Traoré Karfa et al., 2003; Traoré Karfa et al., 2007; Andji et al., 2009), feldspars (Das and Dana, 2003) or chamotte (Djangang et al., 2009). The nature of the mineral phases formed due to the consecutive decomposition of alkaline in this mixture depends on the sintering temperature, their grain size distribution and their concentration (Cypress, 1962; Pytel and Malolepszy, 2000; Traoré Karfa et al., 2007).

In Cameroon, ceramics for building uses 80% of imported products, mainly sanitary wares and floor tiles. Also, their presence over the national territory has increased their use, caused studies of kaolinitic clay deposits (lateritic and hydromorphe soils and sedimentary basin) on their chemical and mineralogical data (Njopwouo and Wandji, 1985; Njopwouo and Kong, 1986; Njoya et al., 2006). These clayey materials concentrate oxides of iron, aluminium and/or silicium, with kaolinite as the predominant clay mineral. Some authors evaluated their possible use as construction materials in the manufacturing of ceramics (Mbumbia et al., 2000; Djangang et al., 2009; Ngon Ngon et al., 2005; Ngon Ngon et al., 2009; Pialy et al., 2009; Ngon Ngon et al., 2012).

In the Douala sedimentary basin, raw materials of the kaolinitic clay deposit of the Bomkoul area have good firing characteristics of ceramics (Elimbi and Njopwouo, 2002). These raw materials have been studied to show their use in the polymerization of the styrene and in the reinforcement of the natural rubber (Njopwouo, 1984). However, least studies related to the mixture of silica and feldspars in kaolinitic clay are known in the ceramics industry.

To that effect, this study aims at highlighting the physicochemical characteristics of kaolinitic and illitic clay of the Missole 2 area in the Douala region and exploring the possible manufacturing of building ceramics from clayey mixture with silica and feldspars.

The first part of the present analysis will be centred on the use of raw materials. Then, porosity, bulk density, and microstructural changes and flexural strengths of fired materials at 1150 °C will be presented.

Materials and Methods

Raw Materials

The study is carried out on kaolinitic and illitic clay coming from the Missole 2 area which is located at about 33 km of Douala, in the eastern part of the Douala sub-basin. The sample was collected from vertical profile of three meters thickness along the well. Approximately 2 to 3 kg of sediments were collected

from a meter-long groove. The sample was analysed for texture, mineralogy and geochemistry.

Physicochemical Analysis

The sample M₂A₃ was dried in an oven at 40 °C for about 24h and then homogenised. One hundred grams of each homogenised sample was grounded to -200 mesh (0.075 mm) in an agate mortar for geochemical and XRD mineralogical study. Grain size was measured following the standard pipetting method for silt and clay fraction (Gale and Hoare, 1991). Deflocculating sample was accomplished by adding sodium hexametaphosphate, and the sand was separated by wet sieving. The size fractions above 0.063 mm were determined by dry sieving. Mineral identification was performed using a Setsys 2400 apparatus from SETARAM 85 equipped with a DSC 1500 heat system with Pt crucibles for thermal analysis, from room temperature up to 1,100 °C using a rate treatment of 10 °Cmin⁻¹ and alumina heat treated at 1500 °C serving as reference material. For XRD, a Brünker diffractometer D8 ADVANCE with a copper source ($\lambda = 1.5489\text{\AA}$) was used, working under 40 kV and 40 mA. The exposure time for qualitative analysis was 2h. Mineralogical phases were identified (JCPDS, 1998). Homogenised powder of sediment sample was chemically analysed for major and trace elements by ICP-AES after dissolution using acid digestion procedure with HF, HNO₃, and HClO₄.

TABLE 1 PARTICLE SIZE DISTRIBUTION (wt.%) OF THE RAW MATERIAL

Sample	d > 2000 μm	63 < d < 2000 μm	2 < d < 63 μm	d < 2 μm	Total
M ₂ A ₃	-	22	33	45	100

TABLE 2 MINERALOGICAL COMPOSITION OF THE RAW MATERIAL

Sample	Kaolinite	Quartz	Illite	Hematite	Rutile	Total
M ₂ A ₃	46.1	27.6	22.4	2.6	1	97.1

TABLE 3 CHEMICAL COMPOSITION OF THE RAW MATERIAL (wt.%)

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	MgO	K ₂ O	CaO	Na ₂ O	MnO	ZrO ₂	P ₂ O ₅	BaO	L.O.I.	Total
M ₂ A ₃	65.15	21.05	5.05	1.63	0.43	0.76	0.81	0.22	0.03	0.08	0.23	0.12	3.9	99.46

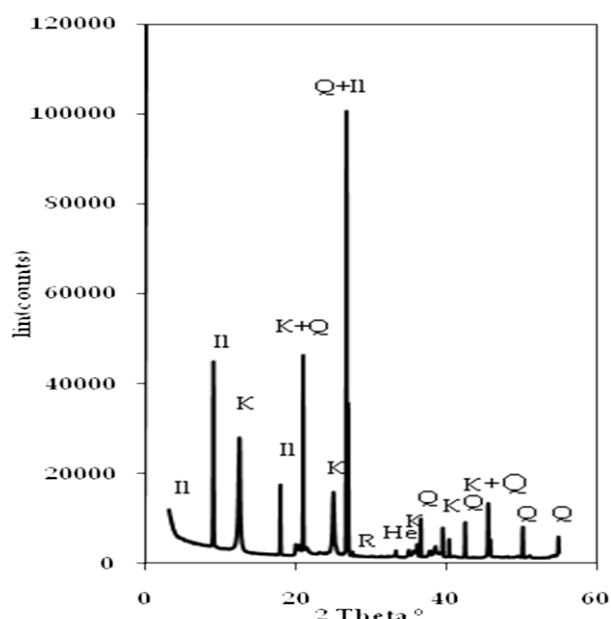


FIGURE 1 XRD PATTERN OF M_2A_3 MATERIAL: Q: QUARTZ, K: KAOLINITE, Il: ILLITE, He: HEMATITE, R: RUTILE

Sample Preparation

The materials used to carry out the experiments consist of M_2A_3 sample and a mixture (Mi) composed of 50% of M_2A_3 , 20% of silica, 15% of Na-feldspar and 15% of mixed-feldspar. In order to optimise their homogeneity, these materials have been grounded and sieved to 40 μm after adding water and having been dried in an oven at 100 °C for about 24h.

The particle size distribution of powders obtained from grounded and sieved materials were characterised by using laser diffraction Coulter granulometer. The diameters of grains are essentially under 100 μm in both materials. The specific surface of M_2A_3 and Mi samples determined using the BET method (Micromeritics Desorb 2300A & Flowsorb II 2300) is respectively 23 and 13 m^2/g . One part of these obtained powders were granulated and successively sieved to 400 μm and 250 μm . Cylindrical pellets (diameter = 10 mm; thickness = 5 mm) were obtained by applying a 40 MPa uniaxial pressure on which parallelepipedic samples (5 mm x 5mm x 10 mm) were cut off after drying at 110 °C for 24 h in order to characterise their densification behaviour. Moreover, parallelepipedic samples with 120mm x 50mm x 5mm were obtained by applying a 35 MPa uniaxial pressure. After drying at 100 °C for 24h, sintering was performed in an electric muffle furnace under air at 550, 750, 850, 950, 1050 and 1150 °C with a heating rate of 5 °C/min on these cylindrical pellets. The parallelepipedic samples were pre-sintered at 300 °C in

an electric muffle furnace under air with a heating rate of 10°C/min and naturally cooled. Sintering was performed in gas muffle furnace at 1150 °C during 90 minutes.

Physical and Mechanical Characterisation

The thermal behaviour was characterised up to 1100 °C on a DI 24 ADAMEL LHOMARY dilatometer at a heating rate of 5 °C/min. Bulk density and open porosity were characterised by the Archimedes method on fired cylindrical pellets under vacuum pump mechanism and flexural strength was determined on the parallelepipedic samples by using a three-point bending equipment (LLYOD instrument, equipped with compressive, tensile and bending tests units) at 0.5 mm/min.

Micrograph Observations

After putting carbon on fracture surfaces, micrograph observations were performed on fractured M_2A_3 and Mi samples, previously heat-treated during 90 minutes at 1150 °C by using a scanning electron microscopy (SEM, Cambridge with a micro-analyser EDS).

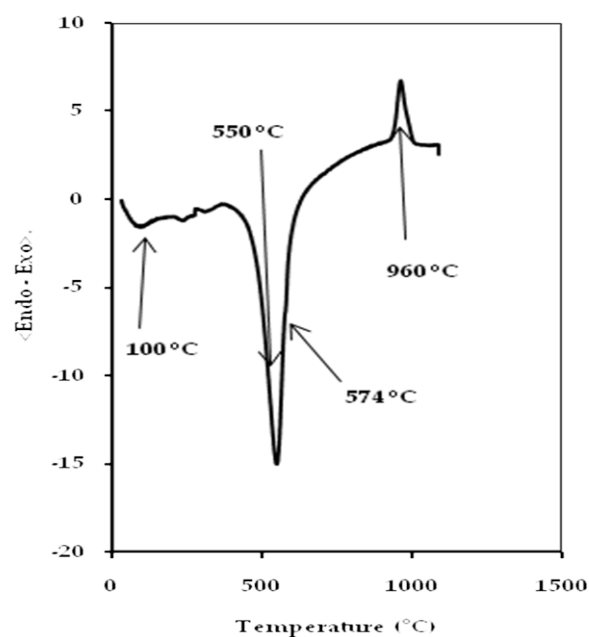


FIGURE 2 DTA CURVE OF M_2A_3 MATERIAL FOR A HEATING RATE OF 10 °C/MIN

Results and Discussion

Texture, Mineralogy and Chemistry

The result of the grain size distribution shows that the Missole 2 sample was entirely composed of clay and silt sized particles with little sand (Table 1). On

average, it was composed of 45% of clay-sized particles, 33% of silt-sized particles and 22% of sand particles. The others investigation techniques used revealed the following aspects:

- XRD analysis showed that M_2A_3 contains essentially kaolinite, illite and quartz as major crystalline phases (Fig. 1). The semi-quantitative mineralogical composition of this powder was determined using Chakravorty and Ghosh method (Chakravorty and Ghosh, 1991). It indicates the following rates: 46.1% of kaolinite, 22.4% of illite, 27.6% of quartz, and 2.6% of hematite and 1% of rutile as accessory minerals (Table 2);
- the DTA analysis curve was obtained from the M_2A_3 raw material highlights a thermal decomposition in two stages (Fig. 2): (i) a loss of structural hydroxyl groups of the clayey minerals at 400 - 600 °C; (ii) a structural reorganisation of the metakaolinite at 900 - 1000 °C (Jouenne, 1990; Lee et al., 1999).
- the chemical composition presented in Table 3 clearly indicates the silico-aluminous nature of the powder M_2A_3 with the predominance of silica.

Dilatometry Behaviour

Fig. 3 shows dilatometric curves of samples M_2A_3 and Mi during heat treatment at 5 °C/min up to 1100 °C. The behaviour of the fired materials is relatively similar. As the temperature rises, four shrinkage stages equivalent to the densification and two dilations are observed:

- Below 110 °C, the first equivalent shrinkage observed in both materials is associated to the physisorbed water;
- A progressive expansion observed between 110–500 °C is mainly governed by the $\alpha \leftrightarrow \beta$ transformation of quartz shown between 550 and 600 °C with low dilation behaviour in both materials; and 600 °C, the second shrinkage is due to the dehydroxylation of phyllosilicates. This phenomenon is much accentuated for Mi and less accentuated for M_2A_3 . The variation of densification during dehydroxylation is related to the high content of hydroxyl phases;
- Between 500 and 600 °C, the second shrinkage is due to the dehydroxylation of phyllosilicates. This phenomenon is much accentuated for Mi and less accentuated for M_2A_3 . The variation of

densification during dehydroxylation is related to the high content of hydroxyl phases.

- Between 900 and 960 °C, the third shrinkage is fast in Mi and is due to the structural reorganisation of the dehydroxylated amorphous phases. An increase of skeletal density without pore elimination is usually associated with this phenomenon (Soro, 2003);
- The fourth shrinkage above 960 °C is steady, and suggests the formation of a significant amount of viscous flux (Pialy et al., 2009) which is rapidly interrupted by the cooling phase at 1060 °C. A low dilation at 574 °C in the cooling phase is associated to the presence of the $\beta \leftrightarrow \alpha$ transformation of the remaining quartz. Firing shrinkage of both materials is similar to those of kaolinitic materials with remarkable presence of silica (Ngon Ngon et al., 2012).

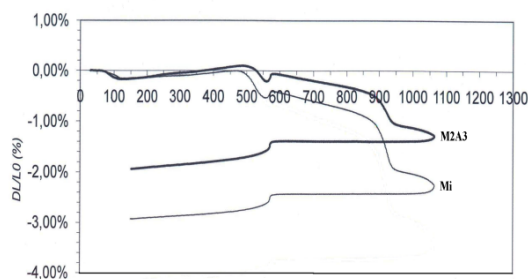


FIGURE 3 DILATOMETRIC CURVE OF M_2A_3 AND Mi MATERIALS

Porosity and Bulk Density

Open porosity and bulk density are shown in Fig. 4a and b and change at various temperatures. With the giving temperatures, open porosity and bulk density of M_2A_3 and Mi ceramics evolve differently before and after 950 °C. Open porosity slightly increases during the first phases of sintering inversely to a slight decrease of bulk density due to the presence of large pores in association with the water departure (Ngon Ngon et al., 2012). Then, there is a steady decrease until 950 °C and rapidly decreases above this temperature. Inversely, in lower temperature bulk density steady increases before 950 °C and then rapidly increases above this temperature with steady increase between 1050 and 1150 °C. This ceramics trend is associated with the sintering of clays (Dondi et al., 1999). However, open porosity of M_2A_3 is higher with all temperatures compared to the mixture while bulk density is most weak in high temperature. The following trend of porosity as described above depends on the amount of additives in clay. During

firing, open porosity decreases with the increase of apparent density when firing temperature increases. The densification during sintering increases with the firing temperature, but also increases with the presence of mineral or chemical additives in clays. These results showed that up to 950 °C bulk density is rapidly enhanced in these materials with pores closing which is usually associated with a large amount of viscous flux (Das and Dana, 2003) notably in the mixture.

Flexural Strength

The mechanical characterisation of M_2A_3 and Mi ceramics after shaping and sintering at 1150 °C were characterised by three-point bending tests up to the rupture. Results showed that average values of fracture stress of M_2A_3 samples were very low (2-8 MPa) and much lower than what was required for manufactured ceramic for building. Besides, ceramics of Mi have average values of fracture stress 2 to 10 times higher than those obtained with sintered clay without additives (15-20 MPa). These values are similar to those required by standards manufactured ceramics for building from clay products (Zanzoun, 1995), and it must be noted that these important strength values are related to the quantity of their addition in clay products.

Apart from their addition role, the strength variation of the fired material is also related to the microstructure of the material (Kingery et al., 1976), mainly the pore fraction and very recently the crystallised of refractory ceramics during sintering (Atkinson et al., 2007).

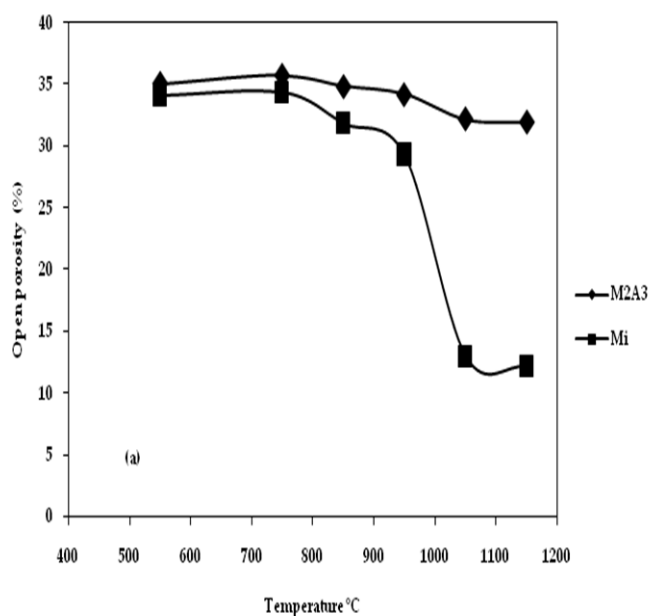


FIGURE 4 OPEN POROSITY (a) AND BULK DENSITY (b) OF M_2A_3 AND Mi AS FUNCTION OF THE FIRING TEMPERATURE

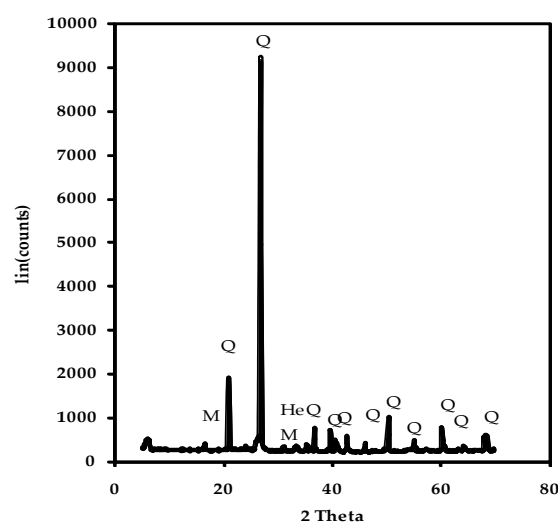


FIG 5a XRD PATTERN OF M_2A_3 MATERIAL HEATED AT 1150 °C: Q: QUARTZ, M: MULLITE, He: HEMATITE

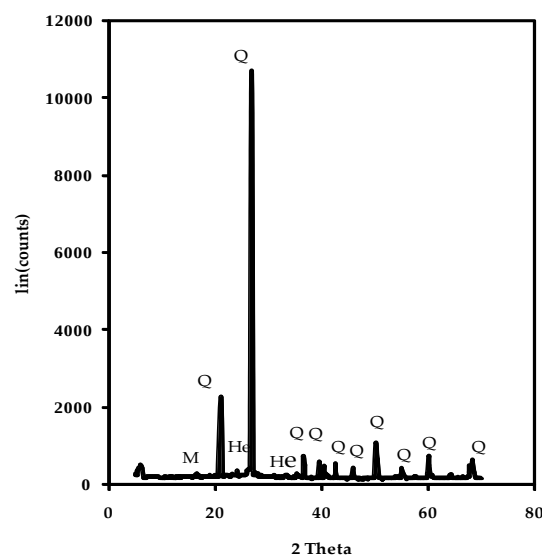


FIG 5b XRD PATTERN OF Mi MATERIAL HEATED AT 1150 °C: Q: QUARTZ, M: MULLITE, He: HEMATITE

Structure and Microstructure of Materials

The crystallised phases identified on XRD diagrams of both samples M_2A_3 and Mi heated for 90 minutes at 1150 °C are mullite, quartz and hematite (Fig. 5a and 5b).

Mullite phases are evident but in weak proportion in the two fired samples coming from structural transformations of illite and kaolinite with increasing temperature. Mullite occurs simultaneously with illite and kaolinite disappearance which supposes a possible link between both phenomena. The formation of mullite in clay materials is evident. Earlier formation of mullite from illite at 1050 °C was observed in Lembo clay (Pialy et al., 2009). The earlier formation of mullite from illite instead of kaolinite has been explained by the effect of potassium and other alkali or alkaline (Slaughter and Keller, 1959). But the formation of primary mullite from metakaolinite during heating up to 1200 °C has been observed (Dondi et al., 1999). For both materials, the presence of additives in Mi product, notably silica and feldspars slightly decreases the mullite content (Fig. 5b).

Hematite phase clearly occurs as an evidence of the presence of iron oxide in both materials. The quartz-cristobalite transformation is no evident but mainly in both materials with initial quartz grain size.

On diffraction patterns, feldspars are not or least detected in Mi product initially composed of 50% of M_2A_3 , 20% of silica, 15% of Na-feldspar and 15% of mixed-feldspar, suggesting their possible smelting without formation of another crystallised phase at 1150 °C. The smelting of feldspar can be developed below this temperature. Differences in densification behaviour of feldspars with the presence of kaolinite and quartz, and with the appearance of dense phases when leucite as future crystalline phase remains in an amorphous state also have been explained (Cohn, 1934; Das and Dana, 2003).

The microstructures and large grains of quartz are distributed within the matrix of fired clay seen on SEM images in the heterogeneous character of microstructures. However, the matrix forms an interconnected network which is different from both materials shown in the SEM photos of Fig. 6a and b for fired materials of M_2A_3 and Mi respectively.

Photo of Fig. 6a of M_2A_3 products shows the large grains of quartz with size of 2 to 100 μm distributed in the volume with the matrix, which presents large and small pores interconnected network where porosity

occurs. Also, fired Mi products (Fig. 6b) are different from M_2A_3 products because the numbers of dense amorphous particles are higher, and large pores with smooth surfaces are evident. However, the number and size of small pores are reduced in fired Mi products. In general, the sintering at 1150 °C changes the microstructural aspect of the Mi product with the abundance of dense phases and the reduced number of pores in the matrix material. This proves the strong interactions of product when densification occurs during sintering.

As far as M_2A_3 product is concerned, Mi product of Fig. 6b contains a higher density of grains, while pores density is greatly reduced and pores surface is characterised by dense glass. The higher flexural strength probably comes from the homogenous microstructural aspect of grains and pores. With addition of 20% of silica, 15% of Na-feldspar and 15% of mixed-feldspar, the individual character of grains is not pronounced in Mi product sintering at 1150°C. The grains are packed up in dense matrix reducing the strong porosity observed in M_2A_3 product, and this certainly explains the great resistance of Mi products. Moreover, the weak flexural strength which characterises the M_2A_3 products is associated to a strong density of pores observed in their matrix (fig. 6a). On this photo, the grains with pronounced individual character are embedded in a porous matrix with soft part form.

The qualitative EDS micro-analysis carried out on inter-granular matrix surfaces shows an abundance of silicium, aluminium and oxygen in these materials (Fig. 6c and 6d). However, aluminium, oxygen, iron and titanium present in the fired product of M_2A_3 are relatively higher than in the fired Mi products. The iron values of M_2A_3 fired product (Fig. 6c) indicate a growth of crystalline phases of iron oxide, which is determined by XRD patterns (Fig. 5) and changes with respect to the quantity. This seems to be correlated to the structural and microstructural transformations during sintering where iron compounds are involved (Andji et al., 2009; Soro, 2003). Potassium and sodium are relatively in higher content on fired Mi products.

Conclusion

The microstructure of ceramic materials obtained by mixing kaolinitic and illitic clay with silica and feldspars is studied by SEM images, porosity, density and correlated to mechanical properties. Besides, the presence of silica and feldspars reduces materials porosity and increases their densification. However,

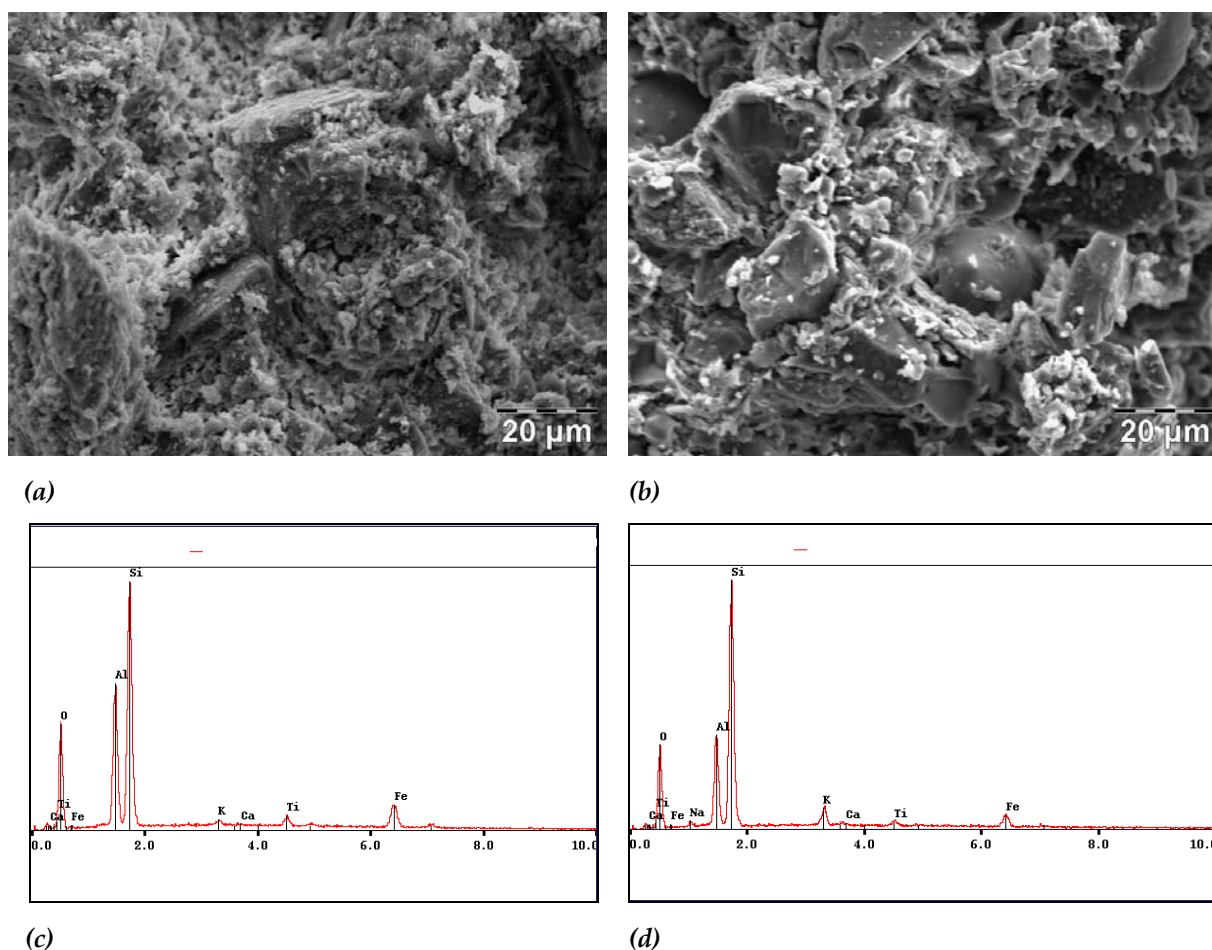


FIGURE 6 SEM OBSERVATIONS OF SAMPLES HEATED AT 1150 °C FOR 90 MINUTES OF M_2A_3 (a) AND Mi (b), AND RESPECTIVELY THE EDS ANALYSIS IN THE INTERGRANULAR MATRIX OF FIRED M_2A_3 (c) AND Mi (d) PRODUCTS

the formation of some crystalline phases up to 1150 °C is crippling to the glass evolution, which significantly increases the mechanical properties. These ceramic materials are least porous than clayey ceramics and can be characterised by the increase of potassium, sodium and iron contents during sintering.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the University of Douala and the geochemical analysis of Geo Labs (Geoscience Laboratories) in Canada. Many thanks are also given to Professor David Smith, Director of the GEMH laboratory at ENSCI, Centre Européen de la Céramique, Limoges, France, and to all his collaborators.

REFERENCES

Andji, JYY, Abba Touré, A, Kra, G, Jumas, JC, Yvon, J, and Blanchart, P. Iron role on mechanical of ceramics with

clays from Ivory Coast. *Ceramics International* 35 (2009): 571-577.

Atkinson, J, Bastid, Q, and Lui. Mechanical properties of magnesia-spinel composites. *Journal of the American Ceramic Society* 90 (2007): 2489-2496.

Charkravorty, AK, and Ghosh, DK. *Journal of the American Ceramic Society* 74 (1991): 1401-1406.

Cohn, WH. *Ber. Dts. Keram. Ges, Germany* 15, p.551, 1934.

Cypress, M. *Bulletin de la Société Française de Céramique*, 55, Paris, France, 1962.

Das, SK, and Dana, K. Differences in densification behaviour of K-and Na-feldspar- containing porcelain bodies. *Thermochimica Acta* 406 (2003): 199-206.

Djangang, CN, Elimbi, A, Melo, UC, Lecomte, GL, Nkombou, C, Soro, J, Yvon, J, Blanchart, P, and Njopwouo, D. Refractory ceramics from clays of

- Mayouom and Mvan in Cameroon. *Applied Clay Science*, 39 (2009): 10-18.
- Dondi, M, Marsigli, M, and Venturi, I. Microstructure and mechanical properties of clays bricks: comparison between fast firing and traditional firing. *Br Ceram Trans* 98 (1999) (1): 12-8.
- Elimbi, A, and Njopwouo, D. Firing characteristics of ceramics from the Bomkoul kaolinite clay deposit (Cameroon). *Tile and Brick International* 18[6] (2002): 364-369.
- Gale, JG, and Hoare, PG. The physical composition and analysis of regolith materials. *Quaternary sediments: Petrographic Methods for the Study of Unlithified rocks*. Belhaven Press, New York, pp. 87-94, 1991.
- JCPDS. International Centre for Diffraction Data, 1998.
- Jouenne, CA. *Traité de céramiques et matériaux minéraux*, Septima, 657pp, Paris, 1990.
- Kingery, WD, Bowen, HK, and Uhlmann, DR. *Introduction to Ceramics*, 2nd ed., John Wiley and Sons/Wiley-Interscience, New York, 1976.
- Lee, S, Kim, YJ, and Moon, HS. *Journal of the American Ceramic Society* 82 (1999): 2841-2848.
- Mbumbia, L, Mertens de Willars, A, Tirlocq J, and Vandeneede, V. Performance characteristic of lateritic fired at low temperatures: a case study of Cameroon. *Construction and Building Materials* 14 (3) (2000): 121-131.
- Ngon Ngon, GF, Yongue Fouateu, R, Bonnet, JP, Bilong, P, and Lecomte, G. Etude de quelques propriétés physiques et mécaniques de deux argiles kaoliniques de la région de Yaoundé (Cameroun). *Silicates Industriels* 70 (11-12) (2005): 33-39.
- Ngon Ngon, GF, Yongue Fouateu, R, Bitom, DL, and Bilong, P. A geological study of clayey laterite and clayey hydromorphic material of the region of Yaoundé (Cameroon): a prerequisite for local material promotion. *Journal of African Earth Sciences* 55 (2009): 69-78.
- Ngon Ngon, GF, Yongue Fouateu, R, Lecomte Nana, GL, Bitom, DL, Bilong, P, and Lecomte G. Study of physical and mechanical applications on ceramics of the lateritic and alluvial clayey mixtures of the Yaoundé region (Cameroon). *Construction and Building Materials* 31 (2012) : 294-299.
- Njopwouo, D. *Minéralogie et physico-chimie des argiles de Bomkoul et de Balengou (Cameroun)*. Utilisation dans la polymérisation du styrène et dans le renforcement du caoutchouc naturel. Thèse Doctorat d'Etat, Faculté des Sciences, université de Yaoundé, 300p, 1984.
- Njopwouo, D, and Wandji, R. *Minéralogie de l'argile kaolinique de Bomkoul (Cameroun)*. *Revue de Sciences et Technique, Série des Sciences de la Terre* I, 3-4 (1985) : 71-81.
- Njopwouo, D, and Kong, S. *Minéralogie de la fraction fine des matériaux argileux de Bomkoul et de Balengou (Cameroun)*. *Annales de la Faculté des Sciences, Série des Sciences Chimiques I*, 1-2 (1986) : 17-31.
- Njoya, A, Nkombou, C, Grobois, C, Njopwouo, D, Njoya, D, Courtin-Nomade, A, Yvon, J, and Martin, F. Genesis of Mayouom kaolin (Western Cameroon). *Applied Clay Science* 32 (2006): 125-140.
- Pialy, P, Tessier Doyen, N, Njopwouo, D, Bonnet, JP. Effects of densification and mullitization on the evolution of the elastic properties of a clay-based material during firing. *Journal of the European Ceramic Society* 29 (2009): 1579-1586.
- Pytel, Z, Malolepszy, J. DTA studies of phases synthesized in the system $\text{CaO-MgO-SiO}_2\text{-H}_2\text{O}$. *Silicates Industriels*, 65 Nr 7-8 (2000): 81-85.
- Slaughter, M, Keller, WD. High temperature phases from impure kaolinite. *American Ceramic Society Bulletin*, 38 (12) (1959): 702-703.
- Soro, NS. Influence des ions fer sur les transformations thermiques de la kaolinite. Thèse doctorat n° 17, Université de Limoges, France, 158p, 2003.
- Traoré, K, Kabré, TS, and Blanchart P. Géhlénite and kaolinite crystallisation from kaolinite and calcite mix, *Ceramic International* 26 (2003): 715-720.

Traoré, K, Blanchart P, Jernot JP, and Moussa G.
Caractérisation physicochimique et mécanique de
matériaux céramiques obtenus à partir d'une argile
kaolinitique du Burkina Faso. *Compte Rendu de
Chimie* 10 (2007): 511-517.

Zanzoun H. Optimisation des étapes d'élaboration de
céramiques à partir d'argiles du Maroc, Thèse de
Doctorat 3^{ème} cycle de l'Université Ain Chock,
Casablanca, 1995.



NGON NGON Gilbert François,
Rue ESSEC-DOUALA, 03 January
2013, Bsc, degree in Earth
Sciences, University of Yaounde I,
Cameroon, 1994, Master degree in
Metallogeny, University of
Yaounde I, Cameroon, 1996. Ph.D, Applied Geology
(Metallogeny), University of Yaounde I, Cameroon, 2007